6 Cases of failures

6.1 Introductory

Any material or building component is subject, by law of nature, to physical or performance decay.
This decay cannot be considered to be pathological as long as it is congruent with the 'average economic life' which characterizes a certain group of products and components under normal maintenance conditions. This type of decay is defined as natural ageing.
On the other hand, when the physical and performance decay (failures) and related anomalies develop unexpectedly in time and quality, and in complete contrast to the conventional concept of natural ageing, a pathological decay exists.
From the phenomenon point of view, the agents and processes leading to a natural ageing process may coincide, even if not necessarily, with those leading to a pathological decay.
Indeed every material reacts entropically to the stimulation of certain external or internal agents (or degradation factors as for instance mentioned in Table 1 of ASTM E 632; see Figure 18). Very often, it reacts even synergically, thus affecting the service life of building components and materials.
This reaction becomes evident through changes observable by visual inspection or by measurements (Table 2 from ASTM E 632; Figure 19). Such changes, if anomalous, may indicate a failure or may be symptoms of an oncoming failure. Anomalies may also be the direct visual expression of a defect affecting a visible element or a part, or be the indirect expression of a defect affecting a part or element which is not directly visible.

TABLE 1 Degradation Factors Affecting the Service Life of Building Components and Materials

- Weathering Factors
  - Radiation
    - Solar
    - Nuclear
    - Thermal
  - Temperature
    - Elevated
    - Depressed
    - Cyclic
  - Water
    - Solid (such as, snow, ice)
    - Liquid (such as, rain, condensation, standing water)
    - Vapor (such as, high relative humidity)
  - Normal Air Constituents
    - Oxygen and ozone
    - Carbon dioxide
  - Air Contaminants
    - Gases (such as, oxides of nitrogen and sulfur)
    - Mists (such as, aerosols, salt, acids, and alkalies dissolved in water)
    - Particulates (such as, sand, dust, dirt)
  - Freeze-thaw
  - Wind
- Biological Factors
  - Microorganisms
  - Fungi
  - Bacteria
- Stress Factors
  - Stress, sustained
  - Stress, periodic
    - Physical action of water, as rain, hail, sleet, and snow
    - Physical action of wind
    - Combination of physical action of water and wind
    - Movement due to other factors, such as settlement or vehicles
- Incompatibility Factors
  - Chemical
  - Physical
- Use Factors
  - Design of system
  - Installation and maintenance procedures
  - Normal wear and tear
  - Abuse by the user

Figure 18. Table 1 from ASTM E 632

The relationship occurring among agents, failures, defects and errors has already been examined in figure 8 of section 2.3.1.

| Observable Change | Visual Inspection | | | | | | | | | | | Measured Change | | | | | | | | | | |

Foundations on shrinkable clay: avoiding damage due to trees

FAILURE: Cracks in foundations and superstructure

DEFECT: Foundations not deep enough where close to trees or to locations of felled trees

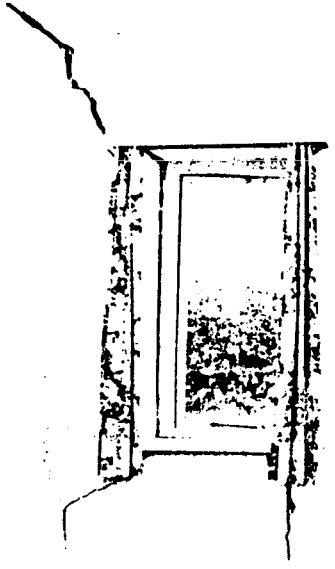


Figure 1 Trees can shrink clay under foundations.

Cracking is fairly common in dwellings on shrinkable clay soils and near to trees. Foundations are affected if trees are close enough for their roots to dry and shrink clay soil below foundation level. This can happen even where foundations are deep enough not to be susceptible to normal seasonal movements. Where trees have been removed, swelling of clay soil, as it slowly wets up, can cause damage: for large trees this swelling may well continue for some years.

If *foundations* are *not below the depth at which clay soils may shrink or swell* due to the proximity or removal of trees, both *foundations and superstructure* may be *damaged*.

PREVENTION

Principle — Foundations on shrinkable clay soils must be designed so that the superstructure will not be damaged by differential shrinkage or swelling.

Practice

- Establish whether soil is shrinkable clay[1]:
  — any location in the shaded areas of Figure 2 is suspect; elsewhere, local knowledge will be a guide.

If so:

- Identify the species of any trees on or adjacent to the site and establish their likely maximum height. Table 1 gives maximum height of some common species:
  — include any mature trees which have been removed in, say, the last 10 years.
- Use Table 1 to establish the rule of thumb for the 'safe' distance that a house with normal foundations should be from any tree (or site of tree) Figures 3a and 3b:
  — if species is above the line, the 'safe' distance is the mature tree height, H, but see footnote to Table 1;
  — If species is below the line, the 'safe' distance is 0.5H.

Table 1

Tree species	Maximum tree height *H* (m)	Safe distance from building
Poplar	24	*H* (see footnote)
Oak	23	
Willow	15	
White Beam/Rowan	12	
Flowering Cherry/Plum	8	
Plane	30	0.5 *H*
Elm	25	
Cypress	25	
Lime	24	
Maple/Sycamore	24	
Common Ash	23	
Beech	20	
Birch	14	
Pear	12	
Apple	10	

Footnote *H* may be reduced to 0.5 H where the 'shrinkage potential'[1] of the clay has been established as medium or low. Tests to determine the properties of clay soil are specified in BS 1377 and are readily available from soil testing laboratories at little cost.

Where tree (or site of tree) is closer to the proposed house than the 'safe' distance:

- Consider bored piles and ground beams[2,3,4] where trees are to remain, or any trees larger than saplings are to be removed, Figure 4.
- Consider, where trees have been or might be removed, providing in addition a suspended ground floor, and:
  — clearance not less than 100 mm below pc ground beams;
  — compressible filling not less than 150 mm thick below beams cast in trenches.
- Design drainage, external services and external works to accommodate differential movements, particularly at points of entry to inspection chambers and to buildings.
- Check that drains, boundary walls and other external works will not be damaged by the action of trees that are to remain.

REFERENCES AND FURTHER READING

1 *BRE Digest* 240, 'Low-rise buildings on shrinkable clay soils'. Part 1.
2 *BRE Digest* 241, 'Low-rise buildings on shrinkable clay soils'. Part 2.

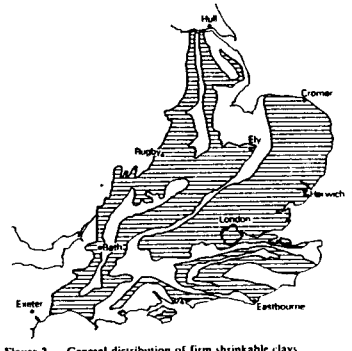


Figure 2 General distribution of firm shrinkable clays — based on BRE records and Institute of Geological Sciences maps.

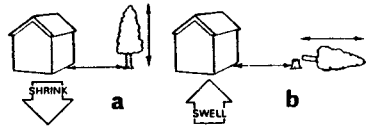


Figure 3 Compare tree height with distance from foundations.

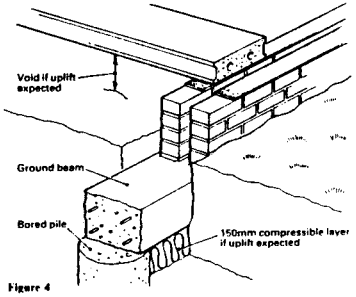


Figure 4

3 *BRE Digest* 242, 'Low-rise buildings on shrinkable clay soils'. Part 3.
4 *BRE Digest* 298, 'The influence of trees on house foundations in clay soils'.
□ *BRE Digests* 63, 64, 67 'Soils and foundations, Parts 1, 2 and 3'.
□ *British Standard* BS 8004: 1986 'Code of Practice for foundations'.
□ *British Standard* BS 5837: 1980: 'Code of Practice for trees in relation to construction'

Figure 20. Example of a Building Research Establishment Defect Action Sheet (DAS 96) - British Crown Copyright 1987

General format

- Component concerned
- Failure description
- Description of evident anomalies
- Description of anomalies which can be monitored through instruments
- Graphic representation (photo, drawing, draft)
- Defect description
- Identification of the agents which caused the defect
- Errors
- Specific fault tree and diagnostic report

Subformat 1

- Component concerned
- Failure description
- Description of evident anomalies
- Description of anomalies which can be monitored through instruments
- Graphic representation (photo, drawing, draft)
- Defect description
- Identification of the agents which caused the defect
- Errors

Subformat 2

- Component concerned
- Failure description
- Description of evident anomalies
- Description of anomalies which can be monitored through instruments
- Graphic representation (photo, drawing, draft)
- Defect description
- Identification of the agents which caused the defect

Subformat 3

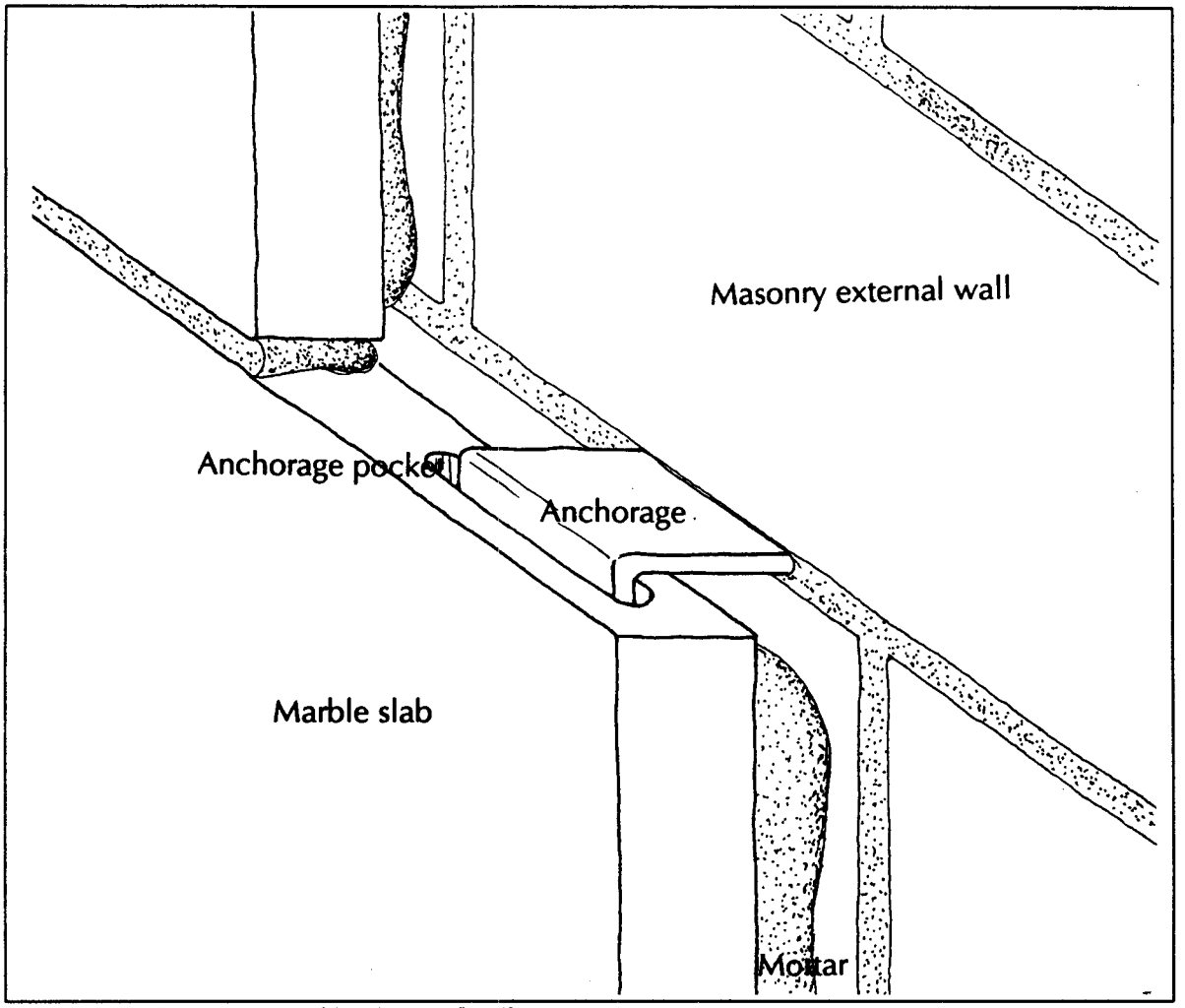
- Component concerned
- Failure description
- Description of evident anomalies
- Description of anomalies which can be monitored through instruments
- Graphic representation (photo, drawing, draft)
- Defect description

Subformat 4

- Component concerned
- Failure description
- Graphic representation (photo, drawing, draft)
- Defect description

CIB W86 - Cases of Failure Information Sheet

Marble facade cladding	EW.1.92
component	code



component description and/or design detail

Cracking and breaking of the marble slab close to the anchorage (fig. 1,2,3,4)

failure

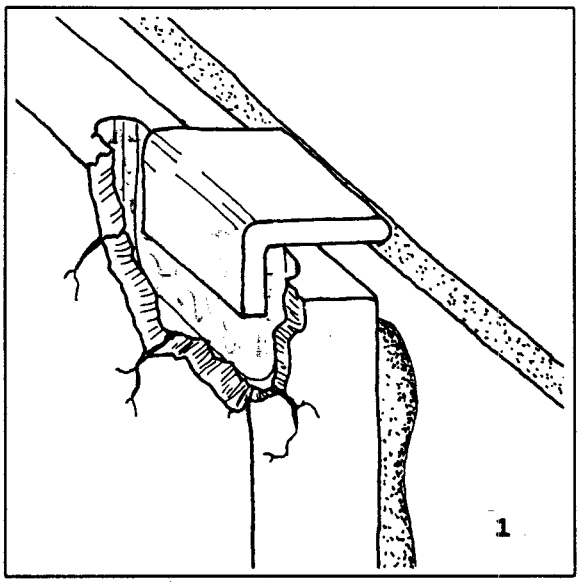
- Corrosion of anchorages
- Insufficient wall thickness of the anchorage's pocket in the marble slab

defect

CIB W86 - Cases of Failure Information Sheet

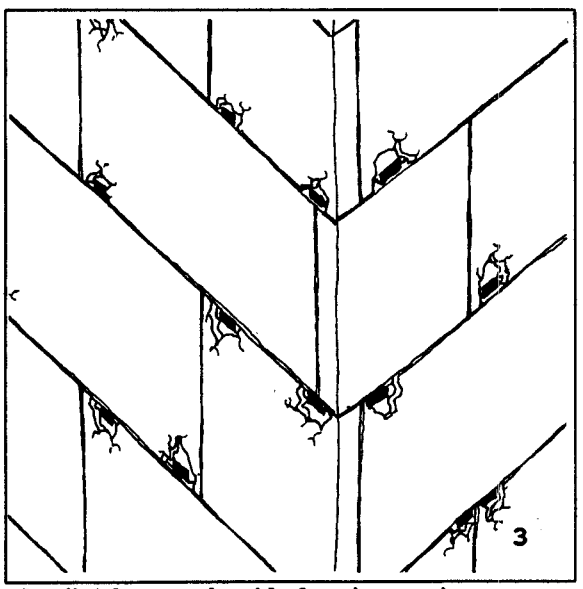
The slab failures are always close to the anchorage (near to the slab corner) and the highest frequency of breaking is concentrated in areas with a higher exposure to the rain (e.g. corners)(fig.3,4)

anomalies and observations

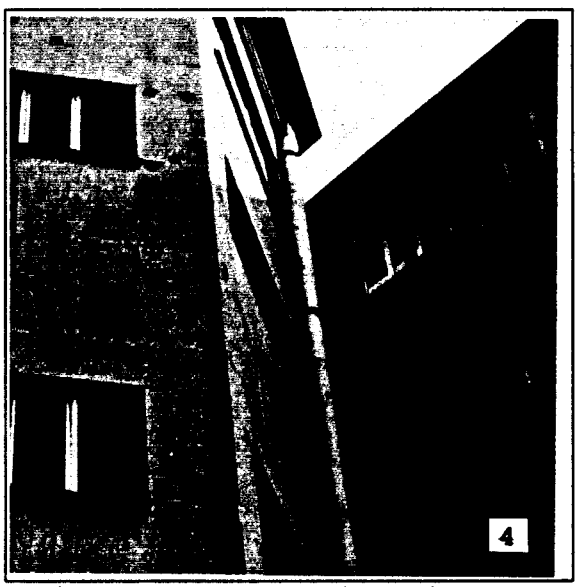


detail (photo, polaroid, drawing, etc.)

detail (photo, polaroid, drawing, etc.)



detail (photo, polaroid, drawing, etc.)



detail (photo, polaroid, drawing, etc.)

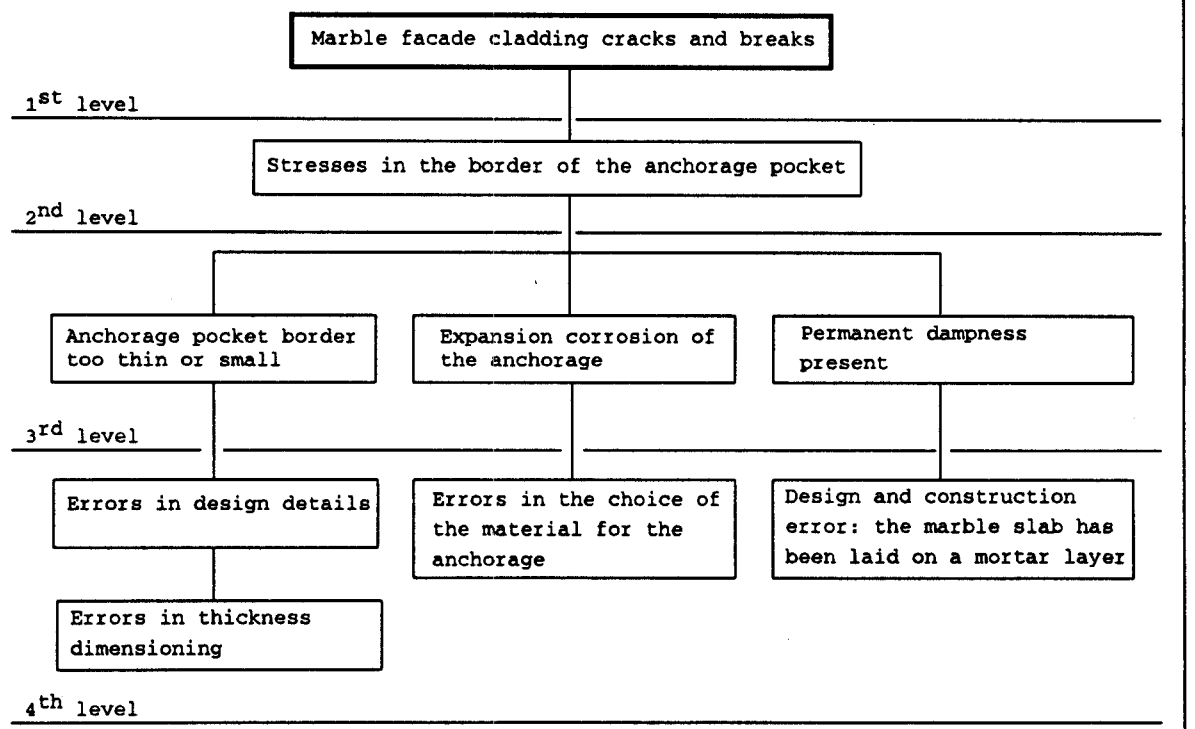
CIB W86 - Cases of Failure Information Sheet

- Rain penetration
- External surface condensation
- Expansive corrosion products

agents which activate the defect

- Wrong choice of the anchorage material (insufficient anti-corrosion protective coating; e.g. zinc coating)
- Wrong (or unspecified) dimensioning of the anchorage pocket border thickness of the marble slab

errors and process phase(s) in which they occurred



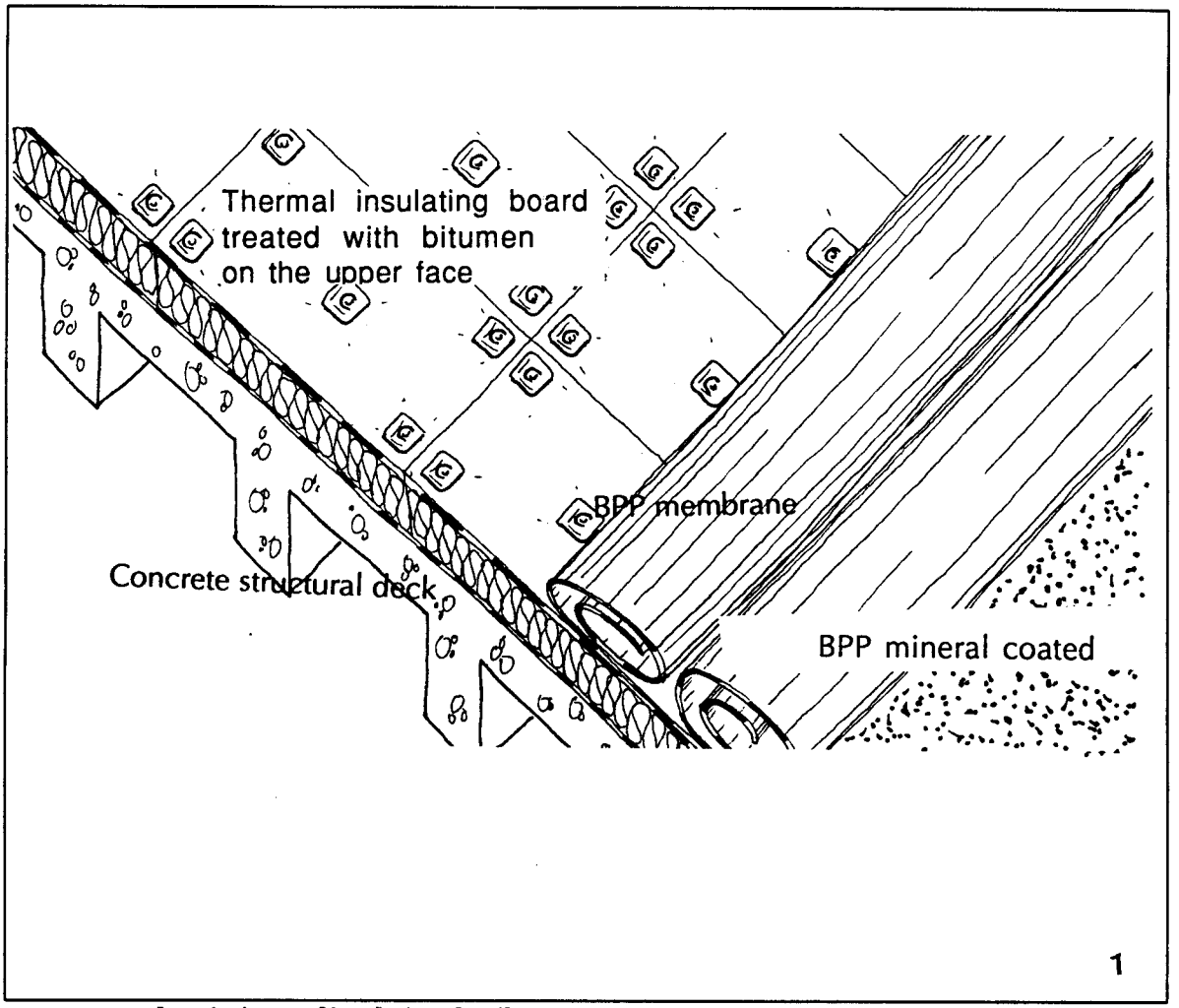
diagnostic report, specific Fault Tree or Fault Tree branch

The building is situated in Milan (near the centre of the town)

notes

CIB W86 - Cases of Failure Information Sheet

Flat Roof	FR.1.92
component	code



component description and/or design detail

Wind-uplift and displacement of the roofing membrane (fig.6,7)

failure

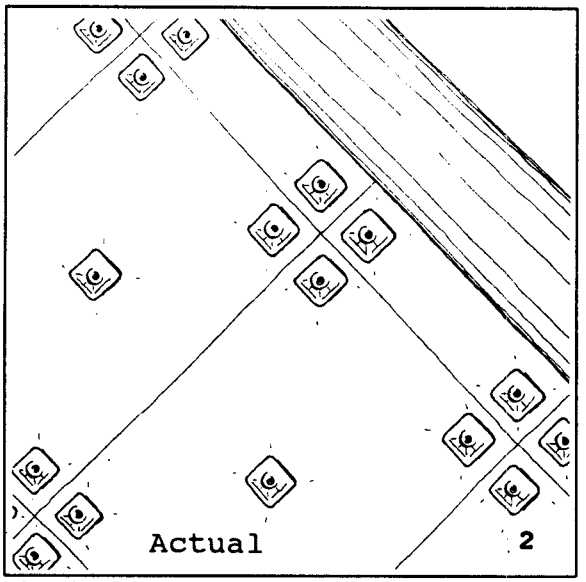
- Inadequate connection between the roofing membrane and the thermal insulation board, for the local wind intensity

defect

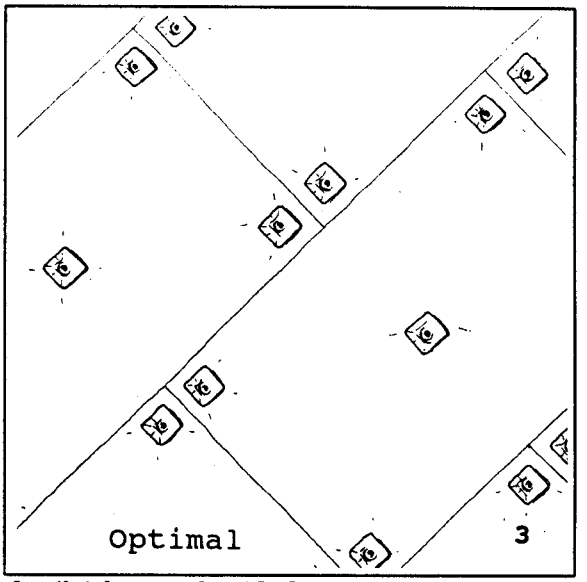
CIB W86 - Cases of Failure Information Sheet

- Total lack of perimeter bonding between the roofing membrane and the vertical insulation boards (fig.4,9)
- The roofing membrane, during the detachment, tears off the superficial coating of the thermal insulation board (fig.4,5,8)
- The fastener washer show no adhesive (the fasteners have been glued to the membrane) (fig.4,5,8)
- Chequered-type laying instead of staggering of joints: 4 mechanical fasteners are concentrated at the same spot and the distance between the fasteners doubles (fig.2,3)

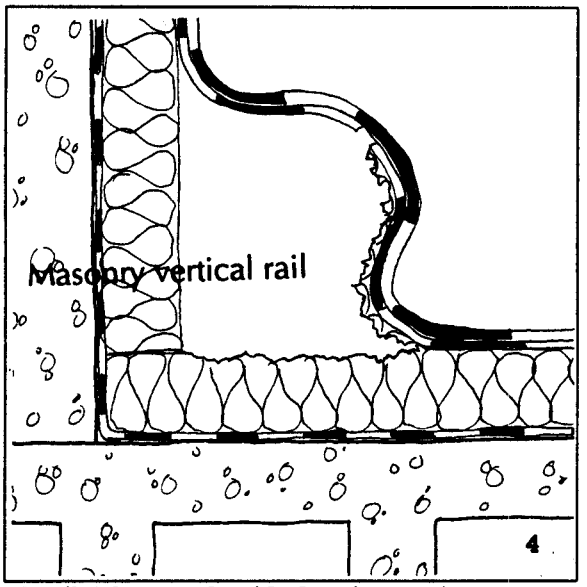
anomalies and observations



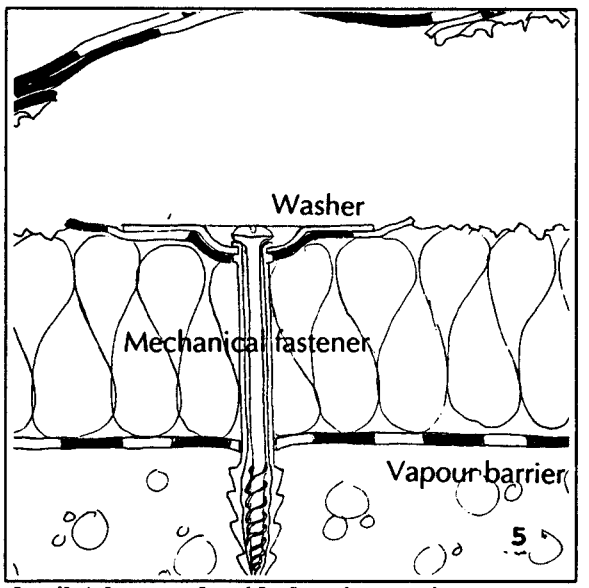
detail (photo, polaroid, drawing, etc.)



detail (photo, polaroid, drawing, etc.)

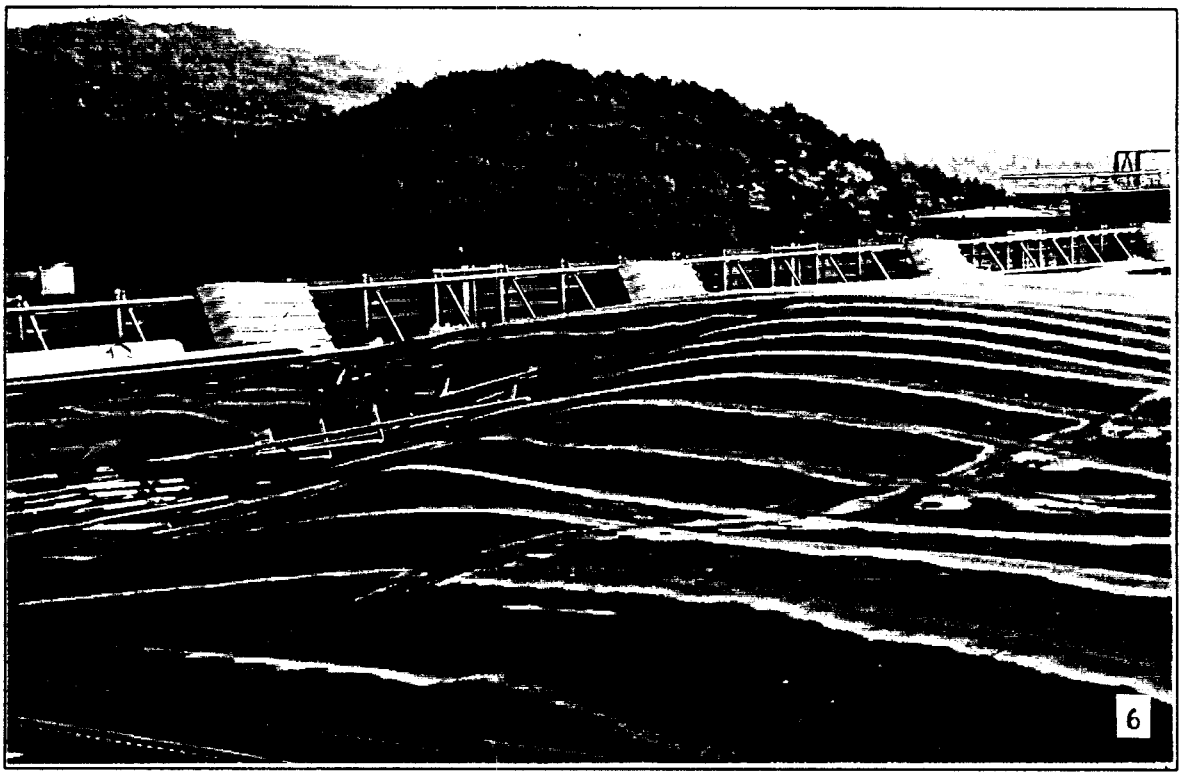


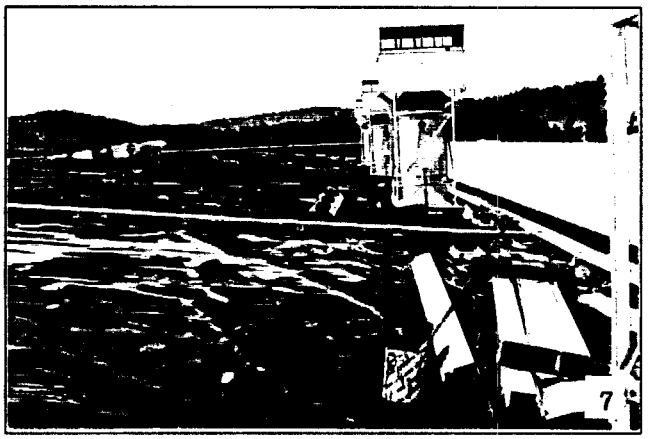
detail (photo, polaroid, drawing, etc.)



detail (photo, polaroid, drawing, etc.)

CIB W86 - Cases of Failure Information Sheet





detail (photo, polaroid, drawing, etc.)

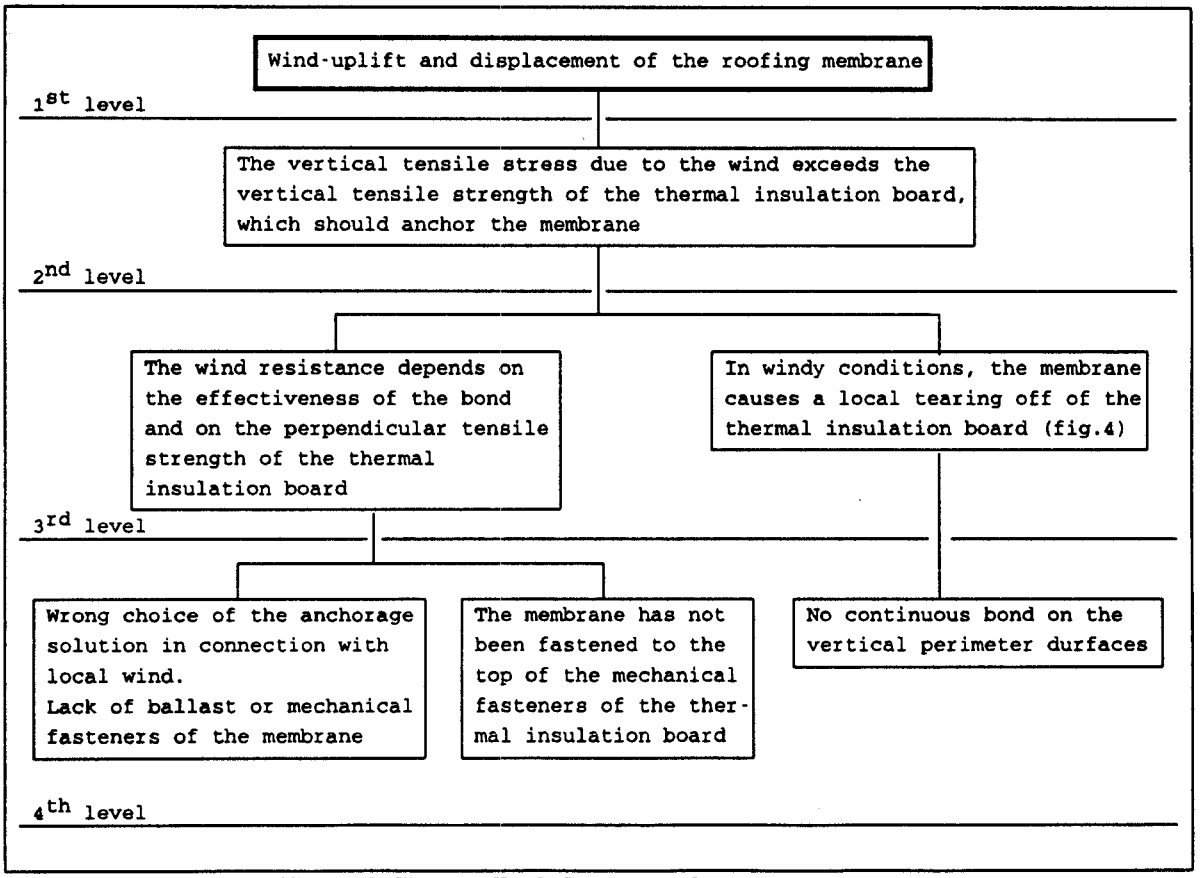
CIB W86 - Cases of Failure Information Sheet

Tensile forces caused by wind pressure drops (negative pressure)

agents which activate the defect

- Lack of analysis of the local wind situation [Design phase]
- Wrong laying of the thermal insulation board (joints not staggered) [Construction phase]
- Inadequate fastening technology applied to the connection between the thermal insulation board and the roofing membrane [Design and construction phases]
- Wrong laying and bonding of the roofing membrane as regards boards and washers [Construction phase]

errors and process phase(s) in which they occurred



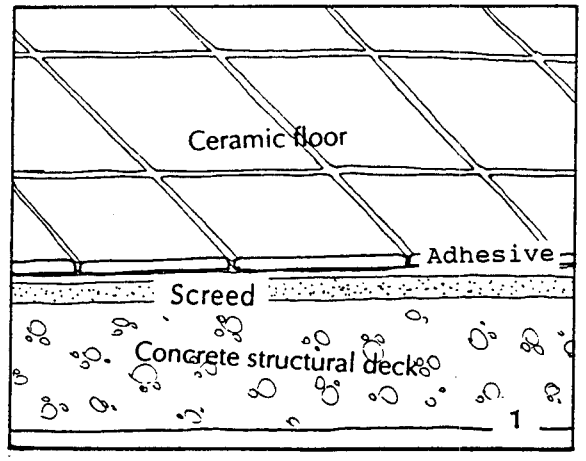
diagnostic report, specific Fault Tree or Fault Tree branch

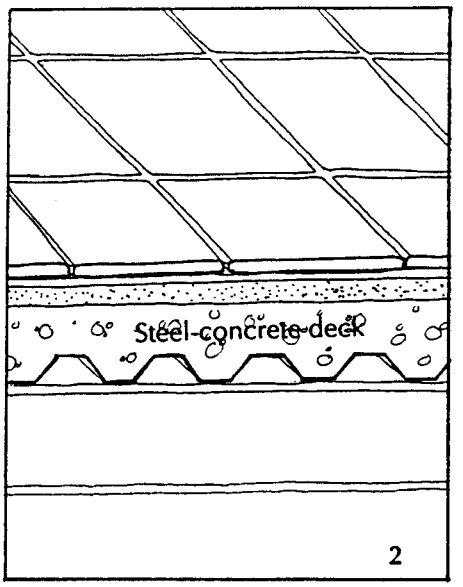
The building (heigth of 26 m) is located in North Eastern Italy, near the sea (2 km); the wind speed often reaches 140-160 km/h

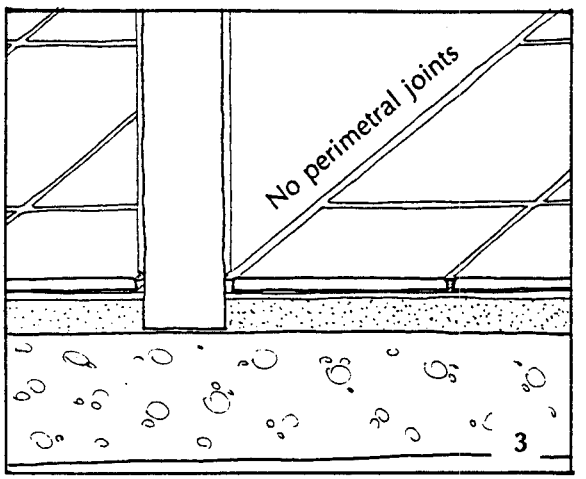
notes

CIB W86 - Cases of Failure Information Sheet

Ceramic Tiles Floor	IHP.1.92
component	**code**







component description and/or design detail

Ceramic tile floor arching (fig.4,5) and detachment (fig.6,7)

failure

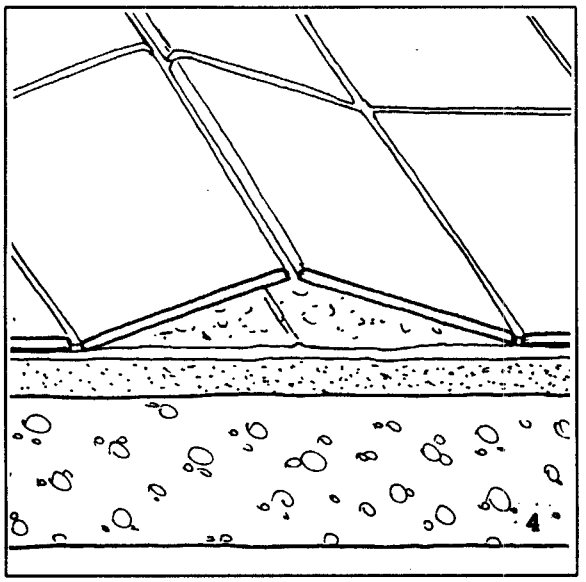
- Insufficient bond between covering and adhesive
- Lack of perimeter movement joints
- Excessive moisture expansion of the tiles

defect

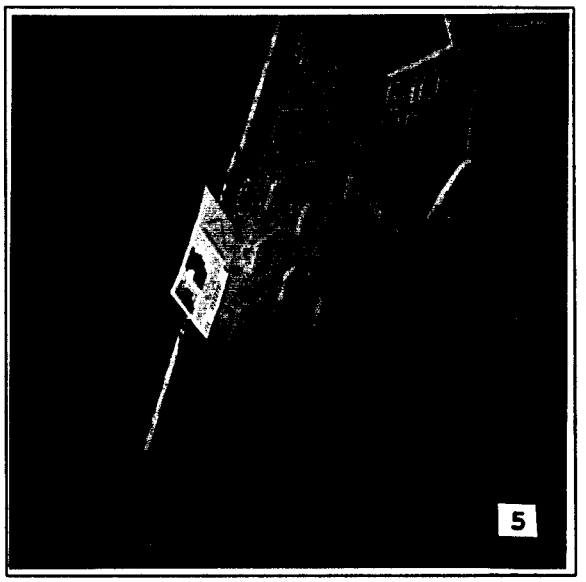
CIB W86 - Cases of Failure Information Sheet

- Lack of movement joints and/or laying areas excessively large
- The lower side of the displaced tiles presents few glue fragments
- The surface of the floor (after the detachment) show the imprints of the lower side pattern of the tiles
- The detachment comes suddenly and shows itself by means of arching in the middle of the room
- The tiles cannot be re-positioned because of their augmented dimensions (excessive permanent expansion due to moisture adsorption)
- The phenomenon appears both on concrete and steel slabs (no influence of slab flexibility)

anomalies and observations

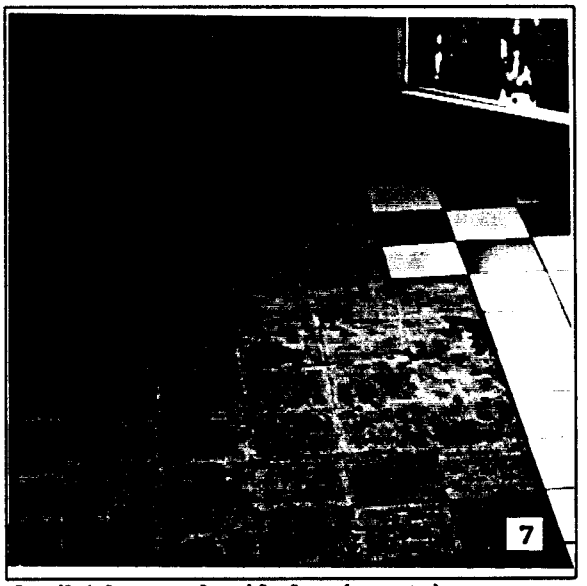


detail (photo, polaroid, drawing, etc.)



detail (photo, polaroid, drawing, etc.)

detail (photo, polaroid, drawing, etc.)



detail (photo, polaroid, drawing, etc.)

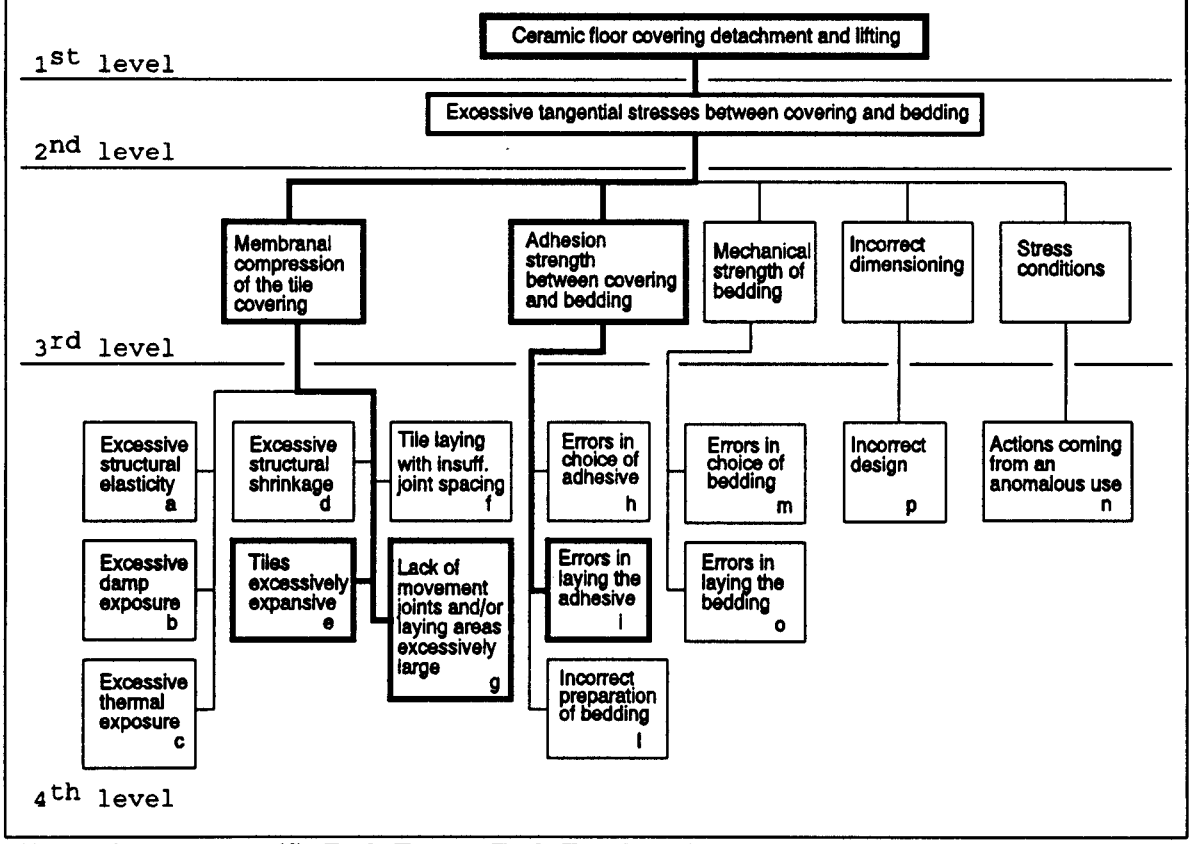
CIB W86 - Cases of Failure Information Sheet

- Relative air humidity activating expansion of ceramic tiles

agents which activate the defect

- Choice of tiles with excessive moisture adsorption [Design phase]
- Omission of the analysis of the effects of the foreseeable expansion of the ceramic tiles: absence of joints [Design phase]
- On site acceptance of ceramic tiles with excessive moisture adsorption [Construction phase]
- Incorrect bonding of tiles [Construction phase]

errors and process phase(s) in which they occurred



diagnostic report, specific Fault Tree or Fault Tree branch

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notes

6.3 Review of failures and defects

As seen before, failures correspond to the termination of an object's ability to perform a required function. It is essential to recall that the defects leading to failure are always connected to human acts performed by different people over the various building stages (ref.[6-1]).
Errors leading to the activation of defects may be due to (ref.[6-2]):

- ignorance or lack of experience leading to underestimating, complicating or neglecting problems;
- forgetfulness, inefficiency, negligence leading to direct mistakes or to omitting quality checks;
- underestimation of risks and excessive self-confidence leading to mistakes like for instance the use of excessively low safety coefficients, or overlooking the importance of specific checks.

The defect, therefore, may occur as a consequence of either a lack of judgement, a lack of care (mistakes) or a lack of precision (errors).
It must be noted that, in engineering, errors can be reduced but not completely eliminated, because of imperfect human activities (ref.[6-3]).
Thus, exceeding given inaccuracy levels turns a given action into a mistake, and generates defects as a result. Their appearance may be due to defects involving layers or elements, or to defects involving the design and manufacture of the building components, or again to defects involving the design and construction of the building system as a whole in relation to the functional interactions occurring in the sub-systems.

6.3.1 Defects involving single layers or products

This type of defect is concerned with the development of layers or elementary parts of a technical solution and is due to wrong choices, poor quality control and mistakes in the manufacture or construction phase. Such defects may lead to pathological results (failures) in the same layer (e.g. a freeze thaw sensitive tile used for the exterior), or in other layers or elements making up the interactive technical solution.
The cases presented in the Failure Information Sheets EW.1.92 / FR.1.92 are related to a wrong choice of materials.
In the first case, the oxidation of brackets leads to local cracking of the cladding panels.
In the second case, the insulation panel under the waterproofing membrane connecting the membrane to the structural support, lacks sufficient vertical tensile and bond strength with respect to windload, thus exposing the membrane to the risk of uplifting and displacement. In this case the failure is linked to a wrong choice of insulating material plus a defective connection - due to bad installation - between the waterproofing membrane and the insulation layer.

6.3.2 Design and construction defects of the building component

In the cases mentioned above, the defectiveness was to be attributed directly to the poor functioning of a layer or a product on which a given reliable solution was based.
In the next cases, the defect originates from planning and detail errors committed with a solution using materials which are not defective in their essence. Such kinds of defects may originate because of wrong or omitted evaluations of the technical solution's service behaviour. An example is the structural collapse of excessively flexible steel structure roofings in which water retention increases until the structure disrupts (so-called 'ponding'). In this case the planning error is the absence of slope of the roofing which could have controlled structural elasticity, or the lack of drains at the pillars (ref.[6-1]).

Sometimes the planning error lies in the absence of control layers for specific risk conditions. For instance, interstitial condensation phenomena can be activated in flat roofings by the lack of a vapour barrier and in ventilated pitched roofs by the lack of airproof layers to prevent infiltration of warm and humid air into the layers of the cover (Figure 21).
In other cases the technical solution's defectiveness might be due to its inability to manage the environment. For example, walls unable to act against the combination of rain and wind, e.g. thin single layer brick walls used in a critical rain/wind index context. Such defects and consequent failures are due to mistakes made at project level before the actual choice of the materials foreseen for the technical solution.
Detail errors at project level or during construction also belong to this category. For example, leakages into the building through perimeter walls due to defective details of the water drains (Figure 22).

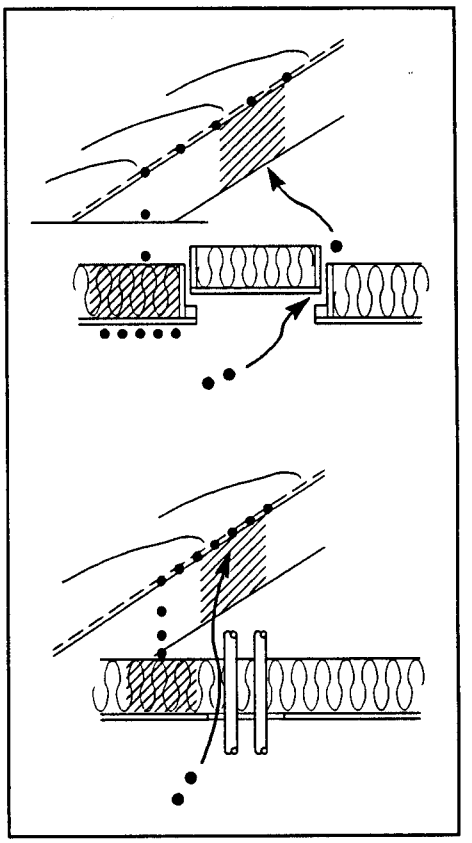

Figure 21. Condensation and mould growth in the roof space (from Building Research Establishment Defect Action Sheet DAS 3)

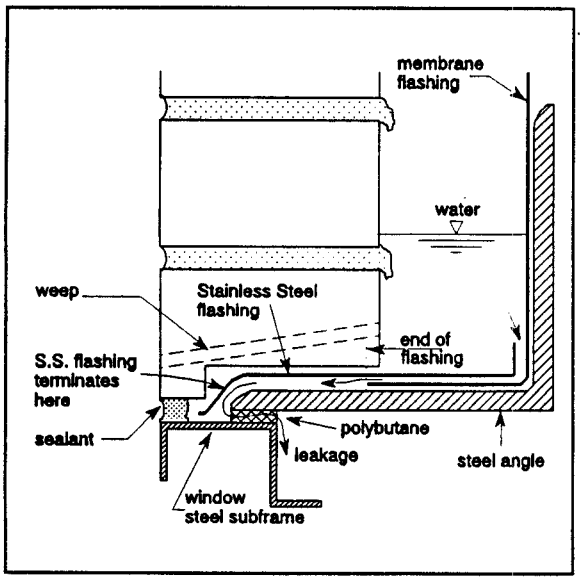

Figure 22. Typical leakage over window frame (lit.[6-1])

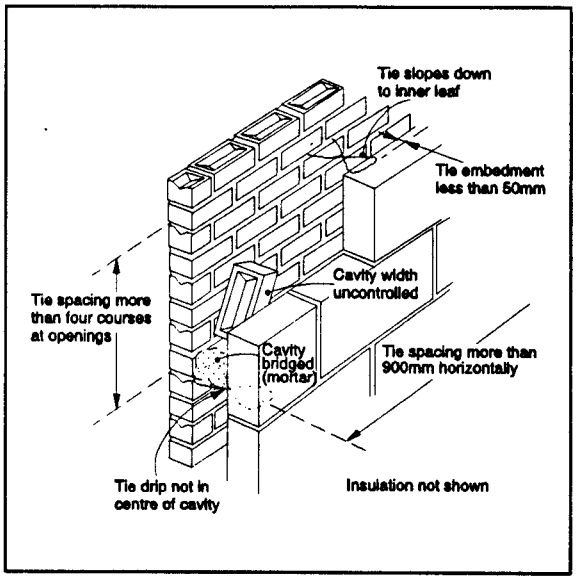

Figure 23. Typical wall tie faults (from Building Research Establishment Defect Action Sheet DAS 116)

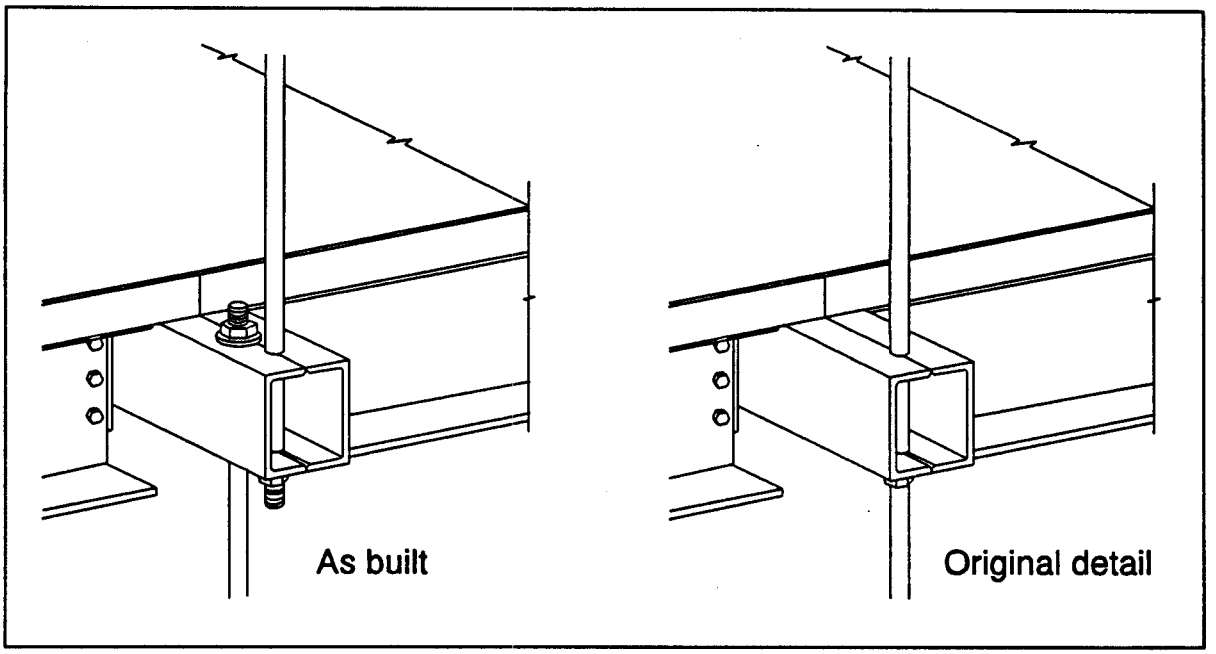

Figure 24. Sketch of the suspended walkways in the Kansas City Hyatt Regency Hotel

As to defects activated in the construction stage, apart from construction errors (Figure 23),there is the possibility of defects originating from changes performed while construction works are in progress.
This is the case of the failures which occurred at the Hyatt Regency Hotel in Kansas City, where a simple hanging walkway failed, taking the lives of 113 people. Figure 24 shows the original detail and the detail as-built. Note how the change of detail contributed to increase the critical aspect which was already present in the original detail.

6.3.3 Design and implementation defects of the building system

This type of defect originates from a lack of knowledge regarding the functioning of the building as a whole and the interactions of the sub-systems.
Figure 25 shows the case of a covering impaired by the pressure generated by an air-heating system in the underlying room. In this case the failure of the waterproofing membrane was due to a defect in the air-heating system (lack of air exhaust openings).

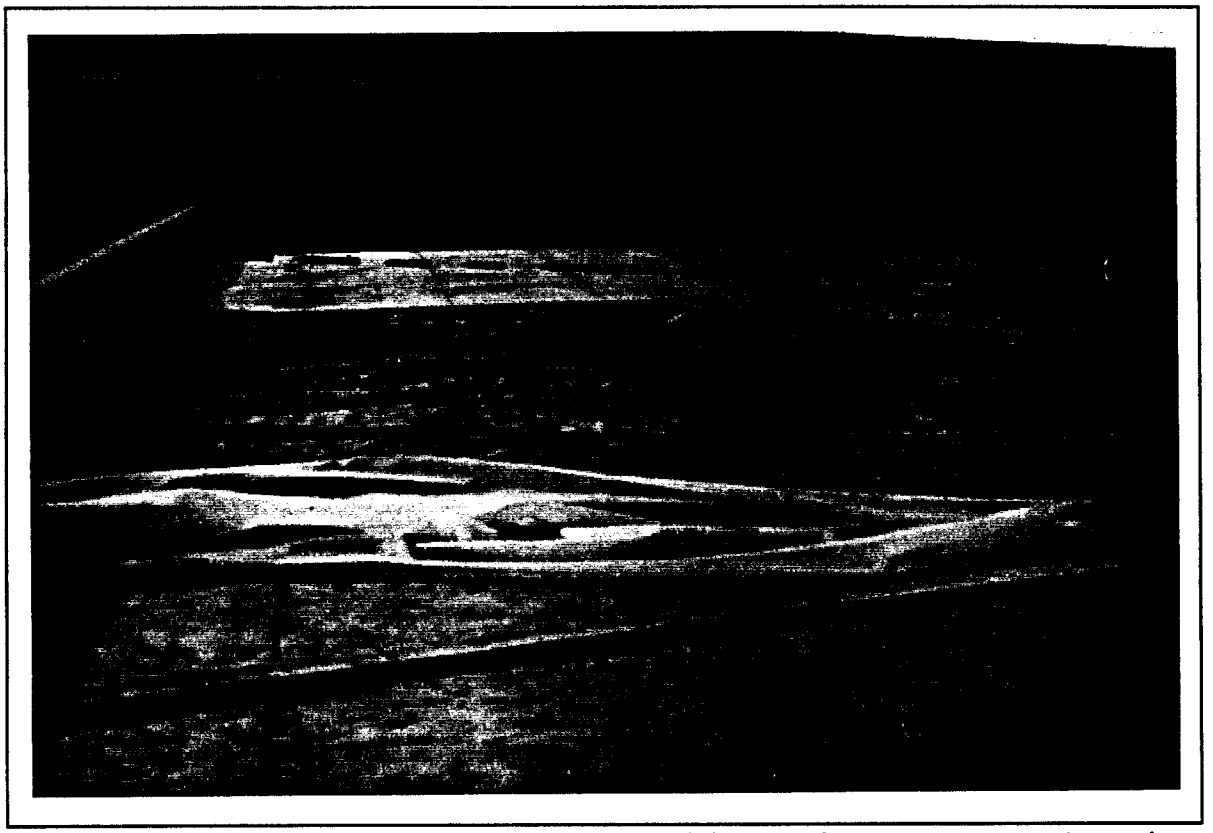

Figure 25. 'Ballooning' of covering, caused by air-heating system in underlying room. Dotted line is the membrane's original position

Surface and interstitial condensation phenomena may belong to the same category and can be due to excessive relative humidity, poor dimensioning or the functioning of the environment ventilation devices.
These defects originate from an excessively fragmented design process which leads to separate solutions to problems with no technical supervision to check the building's overall system behaviour.

6.3.4 Complexity arising from overlapping of errors and defects

The relationship between a defect and a failure may be much more complex than in the cases mentioned already.
This can be detected by fault-tree analysis which will show how overlappings and links between successive events may lead to a failure. The relationship between defect and failure may generate from action and reaction events linked up in series.
A defective rendering, affected by excessive shrinkage (1st defect) and consequently by cracks and fissures (1st failure) activating rain water infiltration into the inner insulation layers, leads to a decreased thermal resistance of such layers (2nd defect), which can lead to surface condensation (2nd failure) as well as to a higher fuel consumption (3rd failure).
The complexity of the pathological picture may be increased by the simultaneous presence of defects acting in parallel with specific synergies for the activation of a given failure.
Such a case is shown in the figure of page 55 (Information Sheet IHP.1.92).
An excessive permanent expansion of tiles (1st defect) linked to the absence of perimeter and field expansion joints (2nd defect) and to poor fixing of the tiles to the support (3rd defect) leads to the displacement of the tiles (failure).
In such a case a defect alone will not necessarily trigger off the specific failure, i.e. the displacement of the covering.
Of course the two typologies (defects acting in series or in parallel) may occur together and produce more complex fault trees.
Given the different types of defects there is virtually no limit to their combinations. Hence it is quite impossible to provide a list of the defects and failures to be found in buildings.
Therefore, a brief review of the defects occurring most commonly in external walls and roofings, namely in the sub-systems affected by a high failure rate, is presented on the following pages.

External walls			
Agent	**Defect**	**Failures**	**Conditions affecting the intensity of action**
Rainwater	Use of unsuitable materials (frost sensitiveness, soluble salt content, sulphate content, high water absorbtion, high hygroscopicity, etc.) Presence of water-retaining cavities Excessive imposed movements (thermal, humid, intrinsic contraction or expansion), lack of expansion joints, etc. See table 'Agents activating inherent movement Differential foundation settlement Architectural feature of the facade causing stagnation, concentrated flow Insufficient wind/rain resistance Incorrect detailing (DPC, flashing)	Water infiltration and leakages Cracks (see table of agents inducing cracks) and water penetrations Moisture reduction of thermal resistance, increased fuel consumption, surface condensation Decay of insulating layers Freeze, inflorescence, efflorescense, subflorescence damages Lime, rust, colour staining, disruption, exfoliation, blistering of surface treatments Metal corrosion and spalling Wood rots	Rain/wind index of the site Facade exposure to rain Freezing/thawing cycles Rising damp Soluble salts ground sources .....
Internal RH	Locally (thermal bridges) or generally inadequate thermal resistance Uncontrolled vapour diffusion through the wall (external layer's vapour impermeability, etc.) Vapour barrier discontinuity Air permeability (air flow through the wall) Insufficient air changes	Surface and interstitial condensation Moisture reduction of thermal resistance Decay of insulating layers Damp staining, mould growth Metal corrosion Wood rots Blistering, exfoliation of external paints	High indoor vapour production / low ventilation rate Intermittent heating Temperature differences between rooms Facade orientation Construction water not evaporated Rising damp Climatology .....
Agents activating inherent movements (thermal, drying shrinkage, etc.)	Lack of expansion joints Unsound joint detailing Bonding of layers with very different inherent mobility Architectural, geometrical feature inducing stress concentrations Local differences in thermal insulation Use of unsound materials (with excessive cyclic or permanent mobility) Use of defective connectors	Cracks Water penetration (see table 'Rainwater') Disruption, detachment, buckling, bulging of elements Joint detail or sealant failures (tearing or squeeze out) Failure of anchorage system	Air/sun temperature exposure Wind-rain exposure Stress condition induced by loads (see corresponding table) .....
Imposed loads	Excessive shortening of the frame: - Frame, beams, slabs elasticity (stress induced within masonry infilling) - Creep deformation Foundation settlement Poor structural design Unsound details	Cracks Consequent water penetration (see table 'Rainwater') Disruption, detachment, buckling, bowing, bulging of wall elements Failure of anchorage system	Stress condition induced by inherent mobility (see corresponding table) .....

External walls			
Agent	**Defect**	**Failures**	**Conditions affecting the intensity of action**
Imposed loads (continued)	No movement joints Architectural, geometrical feature inducing stress concentrations		
Rising damp	Lack or unsoundness of anticapillarity barriers Use of unsuitable materials (frost sensitiveness, soluble salt content, sulphate content, high water absorbtion, high hygroscopicity, etc.) Presence of water-retaining cavities Physical feature of the wall causing concentrated flow evaporation Surface treatment with low vapour permeability	Surface layers decay (efflorescence, inflorescence, subflorescence, freeze/thaw cycles) Mould growth Metal corrosion Wood rots Blistering of paints High internal RH	Wind/rain water (see corresponding table), capillarity, condensation, etc. .....

Flat roofs			
Agent	**Defect**	**Failures**	**Conditions affecting the intensity of action**
Rainwater	Incorrect flashing, roof penetration, expansion joint details Felts cracking, splitting (see table of agents inducing crack failures) Ponding Ponding due to structure deflection Inadequate or bad localised drainage Insufficient slope Insufficient thickness of gravel in inverted roofs	Water infiltration and leakages Membrane blistering, ridging, detachment Moisture reduction of thermal resistence, increased fuel consumption, surface condensation Lime, rust, colour staining, disruption, exfoliation, blistering of surfacial internal surface treatments Decay of insulating and other layers Metal corrosion and spalling Wood rots Chemical attack of membrane by ponding concentration and evaporation Structural collapse caused by progressive ponding, by snow loads Displacement of surface aggregates or external thermal insulation panels (ponding and floating)	Heavy rain and snow Wind action Air pollution (chemical attack) .....
Internal RH	Locally (thermal bridge) or generally inadequate thermal resistance Uncontrolled vapour diffusion through the roof (lack of vapour barrier, vapour retarder, venting, etc.) Vapour barrier discontinuity	Surface and interstitial condensation Moisture reduction of thermal resistance Decay of insulating layers Damp staining, mould growth	High indoor vapour production/ low ventilation rate External temperature Intermittent heating Temperature differences between rooms

Flat roofs			
Agent	**Defect**	**Failures**	**Conditions affecting the intensity of action**
Internal RH (continued)	Air permeability (air flow through the roof) Use of materials sensitive to humidity (inherent mobility, reactiveness) Insufficient air changes in room underneath	Disintegration of surface layers Metal corrosion Wood rots Membrane blistering, ridging, detachment Moisture reduction of thermal resistance, increased fuel consumption, surface condensation	Construction water not evaporated Direct radiation of the membrane to the cold sky Freeze/thaw cycles .....
Agents activating inherent movements (thermal, drying shrinkage, etc.)	Lack of expansion joints Unsound joint detailing Bonding of layers with very different inherent mobility Local differences in thermal insulation Use of unsound materials (with excessive cyclic or permanent dimensional change or with high sensitivity to thermal/moisture expansion) Use of defective connectors	Splitting, ridging, slippage delamination, alligatoring, surfacial treatment erosion of the membrane Water penetration (see table 'rainwater' Failure of anchorage or bonding system	Air/sun temperature exposure Thermal shock Unprotected membrane Stiffening of the membrane by ageing Chemical incompatibility Stress conditions induced by loads (see corresponding table) Material's high sensitivity to thermal, UV, humid exposure .....
Imposed loads	Insufficient resistance of membrane to static and dynamic perforation (hail, traffic) High compressibility of thermal insulation panels Snow overloads at steps in roof elevation: understrength roofs Excessive structural deflection Insufficient resistance to wind uplift forces Differential deflections of structural support Thermal insulation panels not continiously supported	Membrane perforation, splitting Membrane uplift by wind Water penetration (see table 'rainwater') Structural collapse caused by snow overloads Structural collapse caused by progressive rainwater ponding Gravel displacement by wind	Stiffening of the membrane by ageing Mechanical deterioration of thermal insulation panels by moisture Membrane directly exposed to traffic .....

Pitched roofs			
Agent	**Defect**	**Failures**	**Conditions affecting the intensity of action**
Rainwater	Incorrect flashing, roof penetration, expansion joint details Inadequate or bad localised drainage Insufficient or excessive slope Frost sensitivity of slates or tiles	Water infiltration and leakages Lime, rust, colour staining, disruption, exfoliation, blistering of internal surface treatments Decay of insulating and other layers Metal corrosion and spalling Wood rots Dislocation of slates/tiles Disruption of slates/tiles	Heavy rain and snow Wind action .....
Internal RH	Locally (thermal bridges) generally inadequate thermal resistance Uncontrolled vapour diffusion through the roof (lack of vapour barrier, vapour retarder, venting, etc.) Vapour barrier discontinuity Air permeability (air flow through the roof) Use of materials sensitive to humidity (inherent mobility, reactiveness) Insufficient air changes in underside room	Surface and interstitial condensation Moisture reduction of thermal resistance Decay of insulating layers Damp staining, mould growth Disintegration of surface layers Metal corrosion Wood rots Moisture reduction of thermal resistance, increased fuel consumption, surface condensation	High indoor vapour production / low ventilation rate Outside temperature Intermittent heating Temperature differences between rooms Construction water not evaporated Direct radiation of the membrane to the cold sky Freeze/thaw cycles .....
Agents activating inherent movements (thermal, humid shrinkage, etc)	Lack of expansion joints Unsound joint detailing Bonding of layers with very different inherent mobility Use of defective connectors	Failure of anchorage and jointing system Water penetration (see table 'rainwater')	Air/sun temperature exposure Thermal shock Material's high sensitivity to thermal, UV, humid exposure .....
Imposed load	Insufficient resistance to static and dynamic perforation (hail, traffic) Snow overloads at steps in roof elevation: understrength roofs Excessive structural deflection Insufficient resistance to wind uplift forces Differential deflections of structural support	Breaking of roof covering elements Dislocation of roof covering by wind, snow action Water penetration (see table 'rainwater') Structural collapse caused by snow overloads	Roof geometry (snow accumulation and slippage, wind concentration) .....